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ABSTRACT

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Thin films of polyethylene, polystyrene, polypropylene, poly (methyl methacrylate), polycarbonate, poly (ethylene terephthalate), and teflon have been irradiated (2.8 megarad) with γ-rays in air at room temperature. Current measurements with a constant dc voltage have been made at room temperature before and after irradiation. The decay of the transient current has been followed for periods ranging from 10 to 7200 sec, and the n appearing in (1) has been deduced: /583

Author

$$ia = At^{-n} . \qquad (1)$$

It has been found that the decay exponents for these 7 materials are very much altered immediately after irradiation, but the effect gradually decreases. Polystyrene recovered its initial

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state completely, but the others did not, appreciable differences in the n persisting even after 360 hr. The recovery of the decay exponent in these polymers is similar to the recovery in the electrical conductivity. It has previously been reported that doses of 10 to 1000 megarad have little effect on the electrical properties of plastic insulators, but we have found that even 1 megarad has an appreciable effect on the decay of the transient current.

1. INTRODUCTION

A steady voltage applied to an insulator causes a transient (absorbed) current as well as leakage and charging currents. The last very soon falls to zero, but the transient components may persist for many hours.

Explanations such as dipole orientation and space-charge migration have been proposed. It is known that the current is closely related to the dielectric-loss mechanism.

Warner et al [1] reported that the conductivity of plastics such as polyethylene and polystyrene decreases after the voltage has been applied for some time. Ehrlich [2] measured the decay in polystyrene and poly (methyl methacrylate), and discussed the relation to dielectric constant and loss angle.

The magnitude and decay time of the transient current are functions of temperature and polymer type. For relatively short times, it is found [3] that the relation is

$$ia = At^{-n}, \tag{1}$$

in which ia is the transient current at time t after the application of the voltage; A and n are constants.

Munick [4] measured n at room temperature for polyethylene, polystyrene, and teflon; he found that n remained almost constant for a given polymer at a fixed temperature but that it was a function of the temperature.

The n generally found for the common plastic insulating materials range from 0.4 to 2 within certain temperature limits [5], but very few values are to be found in the literature. It is also not certain whether the current is affected by the previous treatment of the polymer.

We have examined 7 materials and have measured n before and after γ-irradiation.

2. MATERIALS AND METHODS

2.1 Materials and Preparation of Films

The 7 polymers (Table 1) were used as films; those for polystyrene and poly (methyl methacrylate) were made by dissolving the commercial material (pellets) in chloroform, the solution being poured onto a glass plate and the solvent allowed to evaporate. The other materials were used as films commercially available. The specimens were circles (88 mm diameter), which were dried in a desiccator over calcium chloride. /584

Table 1. Thickness and specific gravity of samples.

Sample	Thickness (mm)	Specific gravity (g/cm^3)	Remarks
Polyethylene	0.06	0.961	
Polystyrene	0.06	1.040	
Polypropylene	0.06	0.904	
Polymethyl methacrylate	0.12	1.181	
Polycarbonate	0.06	1.202	Makrofol
Polyethylene terephthalate	0.09	1.396	Mylar
Polytetrafluoro-ethylene	0.10	-	Teflon 7

Circular electrodes and guard rings of aluminum foil (0.02 mm thick) were attached to the films with petroleum jelly.

The electrodes had an effective area of 19.6 cm^2; the gap between electrode and guard ring was about 8 mm. This gap was cleaned by treatment with methanol, to eliminate surface leakage.

2.2 γ-Irradiation

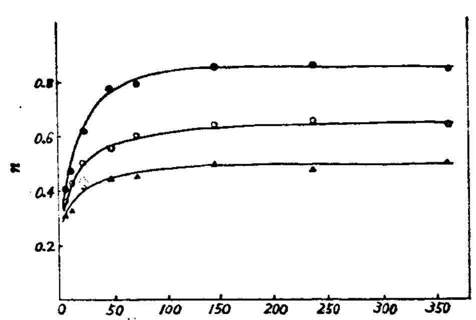
The source was 300 curies of Co^{60}; the irradiations were done in air (35 % relative humidity) at 14°C. Dose rate: 28 krad/hr, integral dose 2.8 megarad.

2.3 Measurement of Transient Current

The electrodes already described were used to make this measurement before and after the irradiation. The specimen was kept in a thermostat at 23 ± 0.5°C and 35 ± 3 % relative humidity.

The current was measured with a Takeda Riken TR-81 vibrating-reed electrometer; the applied voltage was 92 V.

The current was measured for about 120 min (7200 sec).



Time after irradiation (hr)

●: Polystyrene, O: Polytetrafluoroethylene,
Δ: Polyethylene terephthalate

Fig. 1. n vs. time after irradiation.

Table 2. n before and after irradiation.

Sample	Before irradiation	360 hours after irradiation
Polyethylene	0.7	0.45
Polystyrene	0.85	0.85
Polypropylene	0.55	0.4
Polymethyl methacrylate	1.0	0.75
Polycarbonate	0.7	0.45
Polyethylene terephthalate	0.7	0.5
Polytetrafluoroethylene	0.8	0.65

3. RESULTS AND DISCUSSION

3.1 Transient Current in Initial Material at Room Temperature

Figure 2, parts a to g, shows the decay over a period of 7200 sec. Equation (1) fits the current very closely for the time range used for all the materials; n is almost constant for each material, the values for polyethylene, polystyrene, poly (methyl methacrylate), and teflon are 0.7, 0.85, 1.0, and 0.8 respectively. Bearing in mind the difference in temperature, these agree well with Munick's results [4].

The field strength in these tests was 9.2 to 15.3 kV/cm, whereas Munick used values 10 to 15 times larger. It would seem that the field is without effect on n over this range.

3.2 Transient Current After Irradiation: Recovery in n

Tests immediately after irradiation showed that the rate of decay was very much less (n was very much smaller).

The voltage was applied subsequently at specified times for the above period (about 7200 sec); n tended to increase, at first rapidly and then more slowly.

The n for polystyrene returned to its original value after about 150 hr, but the other materials did not regain their original values even after 360 hr; n was much altered. Figure 1 gives some of the results.

Farmer et al. [6, 7] have described the behavior of the conductivity and the transient current for irradiated plastics; our results agree to a certain extent with theirs.

Table 2 gives n at 360 hr after the irradiation; Fig. 2, parts a to g, shows the decay curves.

Apart from polyethylene, irradiation reduced n; further, the /586
magnitude of the current was reduced by irradiation for poly (ethylene terephthalate) and polycarbonate.

It is generally believed that very high doses (10 to 1000 megarad) are needed in order to produce clear-cut results with polymers, especially as regards electrical parameters. It is stated that the volume resistivity and dielectric constant are hardly affected until the mechanical properties show some change [8]. Suzuki et al. [9] examined the ac characteristics of plastic insulators and found that mylar and polystyrene

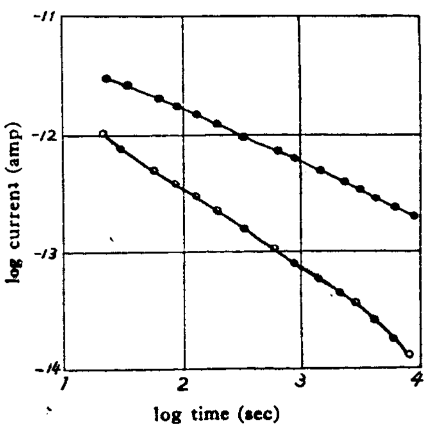


Fig. 2-(a).

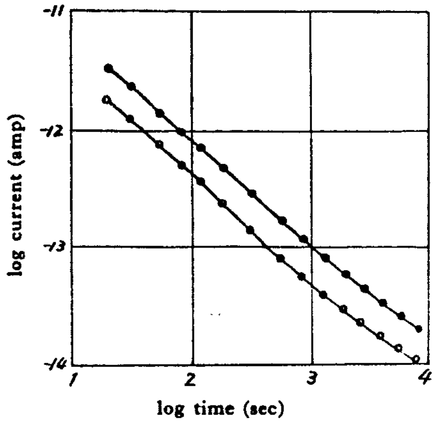


Fig. 2-(b).

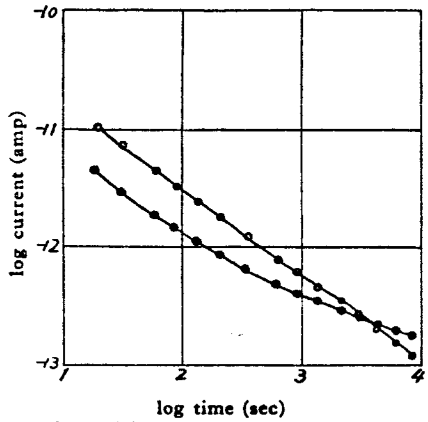


Fig. 2-(e).

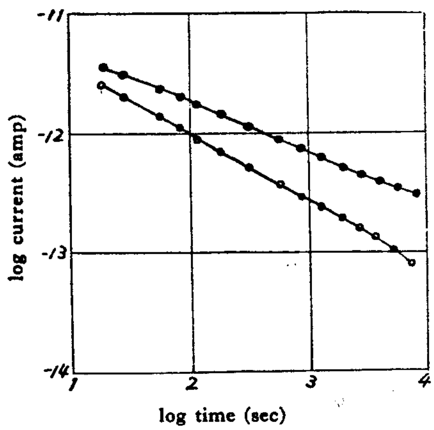


Fig. 2-(c).

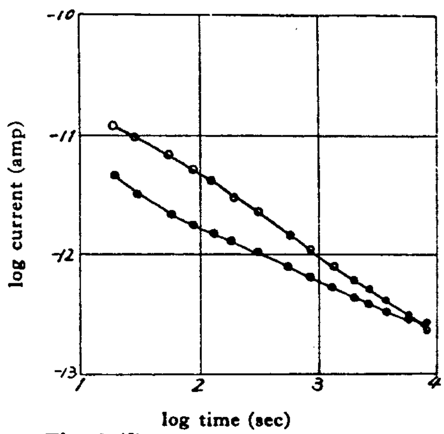


Fig. 2-(f).

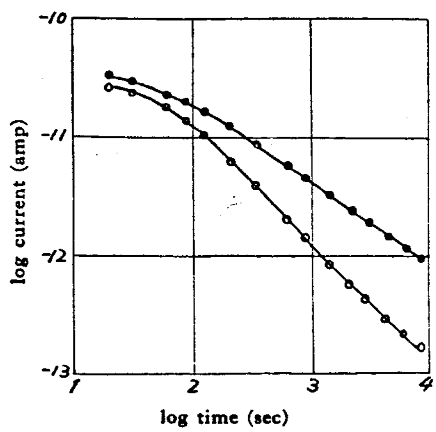


Fig. 2-(d).

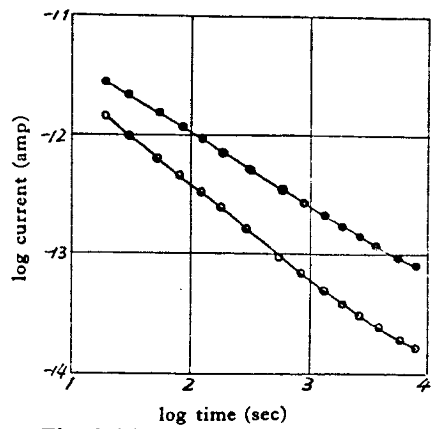


Fig. 2-(g).

○: before irradiation, ●: 360 hr after irradiation

Fig. 2. Logarithm of the current at 23±0.5°C vs. logarithm of the time after application of voltage.

are stable up to 100 megarad, with not much change for polycarbonate (macrofol) in the range 10-100 megarad. Further, it is known that similar doses to polyethylene in air produce hardly any change in the dielectric constant, although there is some increase in the loss angle.

The transient current shows a pronounced response to 1 megarad of γ-irradiation even in the case of the highly resistant materials; n was much altered. This effect is of considerable interest.

The reason for the change is not clear, but the matter is now under detailed study.

Irradiation under vacuum produces rather different effects, which will be dealt with in a forthcoming paper.

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